

LA-UR-21-23850

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Title: Development in Neutron Scattering at WNR using Dual n-gamma Detection

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Intended for: Presentation for P-Division Physics Cafe series

Issued: 2021-04-20

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Welcome to Physics Café



Keegan Kelly, P-3:

“Developments in Neutron Scattering at WNR using
Dual n - γ Detection”

April 22nd, 2021

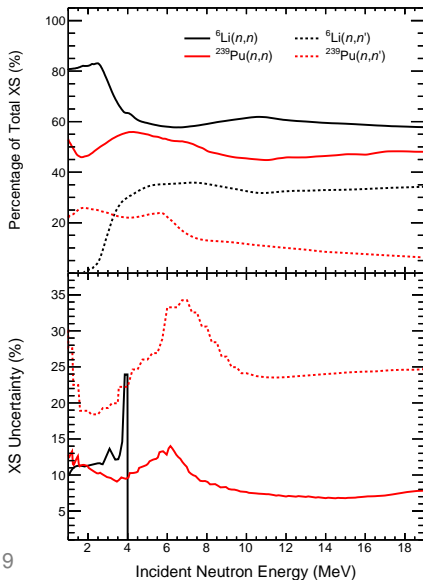
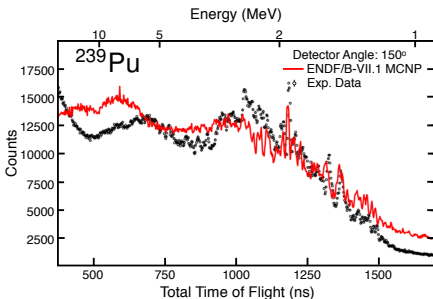
Outline

- Neutron scattering data analysis development with liquid scintillators at WNR
 - correlated $n\text{-}\gamma$ measurements from neutron scattering
- Ideal detector search, challenges, and array development
- Potential for correlated cross section measurements



Scattering is the Most Probable n Reaction, but Cross Sections have Large Uncertainties

- Scattering is usually the most likely neutron interaction
- Uncertainties are prohibitive for simulation accuracy
- Scattering cross sections are the evaluation “trash bin”[†]

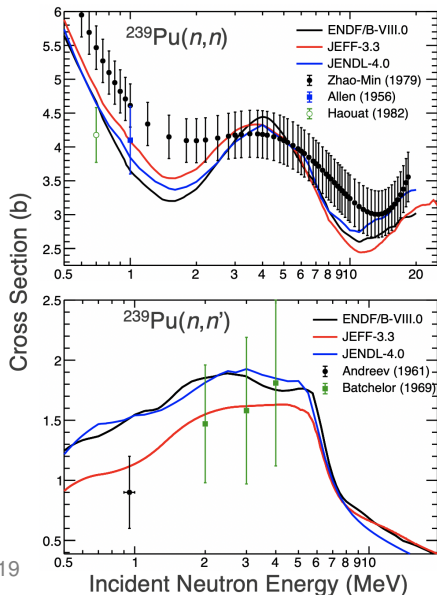
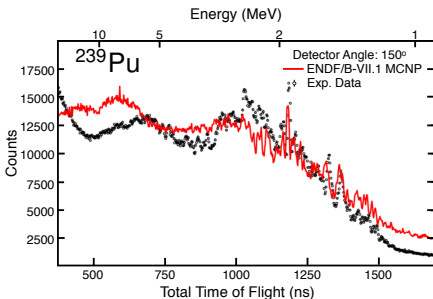


[†]D. Brown, The Nuclear Data Pipeline, WANDA2019



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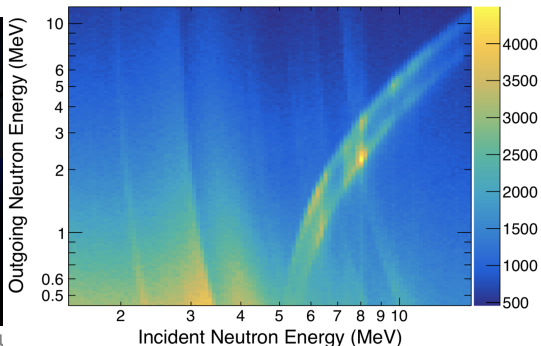
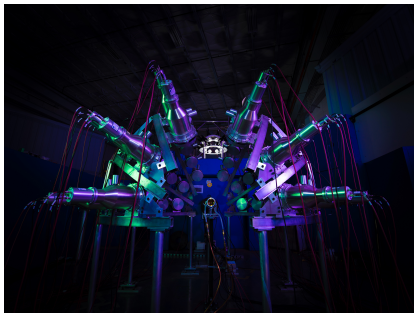
[†] D. Brown, The Nuclear Data Pipeline, WANDA2019



Liquid Scintillators Used for Initial Studies

- Able to leverage data collected from other experiments using the Chi-Nu liquid scintillator array
 - High statistics, to better guide data analysis
 - Difficult to obtain high statistics with trial detector purchases
- Start with easy case: natural carbon

Begin by simply looking for n - γ coincidence in post-processing analysis



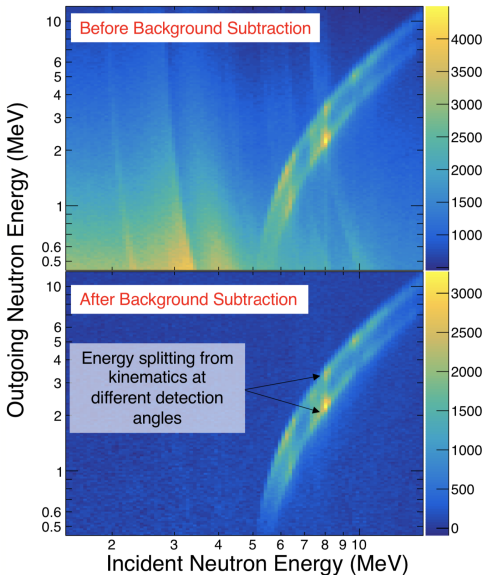
Random Coincidence Backgrounds Eliminated

- Random coincidence rates derived from Poisson probabilities for *uncorrelated* detection rates [†]
 - true coincidence rate must be low
- Calculate the total probability for:
 - Detecting a γ at time t_γ
 - Not detecting n over coinc. time $t_n - t_\gamma$
 - Detecting n at time t_n

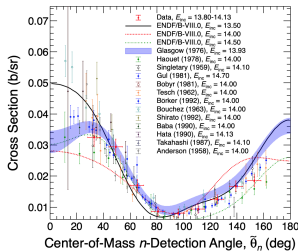
$$\begin{aligned}\text{Coinc. Rate} &= r_b = r_\gamma r_n \Delta t \\ &\Rightarrow b = \frac{\gamma n}{N_{t_0}} \\ &\text{with } \gamma, n = \text{counts}\end{aligned}$$

- Works remarkably well here

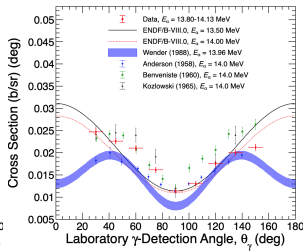
[†]O'Donnell, NIMA 805 (2016) 87



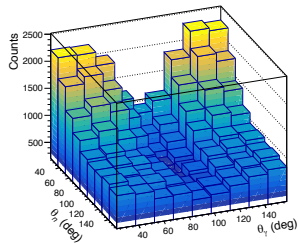
Extract n , γ , and Correlated n - γ Distributions



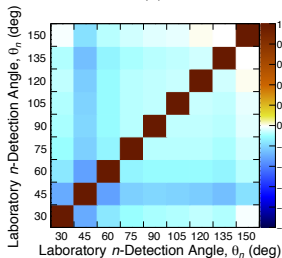
(a)



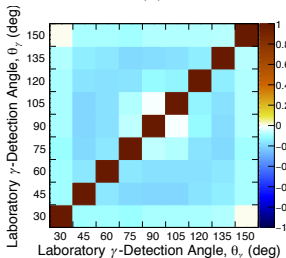
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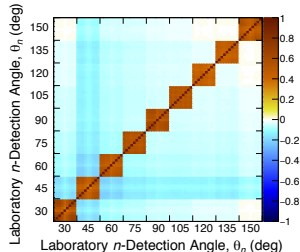
(c)



(d)



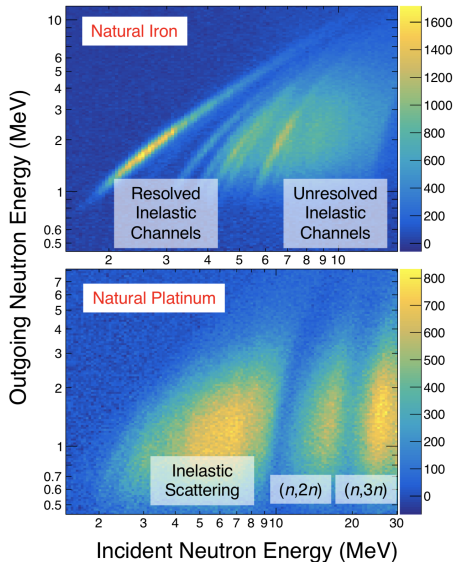
(e)



(f)

Sensitive to *All* n - γ Producing Reactions

- Fe levels are reasonably dense
- The liquid scint. time resolution allows for ^{56}Fe low-lying state separation
- Natural Pt shows inelastic scattering, $(n,2n)$, and $(n,3n)$ reactions, with separation
- Elastic scattering data also exist from these measurements
- Potential for correlated measurements of these different cross sections



Search for the Ideal n - γ Detector

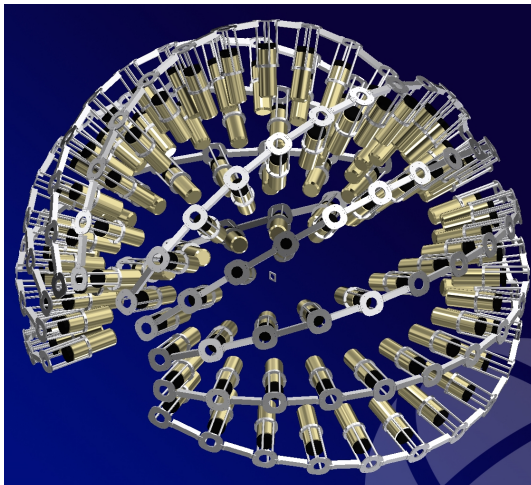
	Time Res.	γ Energy Res.	PSD	Pulse Length	n Energy Range	γ Energy Range	Det. Efficiency
HPGe	5-10 ns	<1%	N/A	>100 μ s	N/A	Det. Dep.	Only γ
Liq. Scint.	1 ns	Bad	Limited	10-20 ns	>0.7 MeV <12 MeV	Poorly Defined	Both Obs. $n > \gamma$
CLLBC	1.5 ns	4%	Near Perfect	4 μ s	Thermal – 10 MeV	>0.2 MeV <7 MeV	Both Obs. $\gamma \gg n$
CLYC-7	1.5 ns	4.5%	Near Perfect	4 μ s	>1 MeV <10 MeV	>0.2 MeV <7 MeV	Both Obs. $\gamma > n$
CLYC-6	1.5 ns	4.5%	Near Perfect	4 μ s	Thermal – 10 MeV	>0.2 MeV <7 MeV	Both Obs. $\gamma > n$

- CLYC-6 possess all necessary characteristics, with some drawbacks
 - Semi-long waveforms: 1.5" detectors to reduce count rates
 - PSD-overlap of ${}^6\text{Li}(n,t)$ and ${}^{35}\text{Cl}(n,p)$: Increased target-detector distance
 - Need large number of detectors to have sufficient efficiency



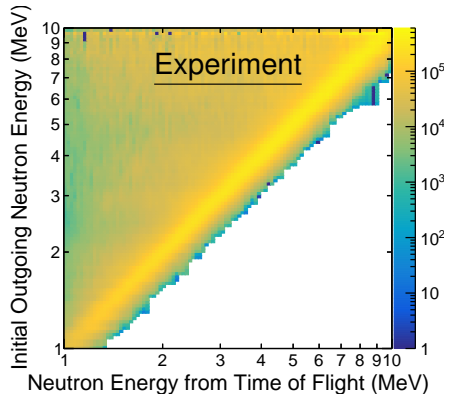
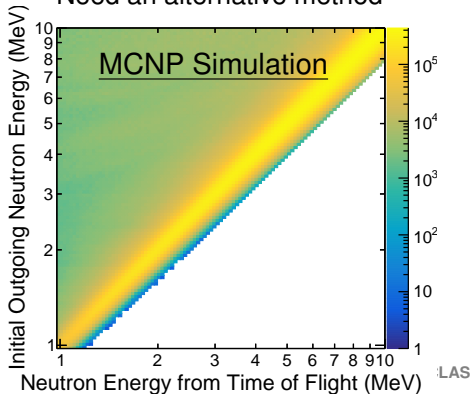
Array Structure Development is in Progress

- CAD design work in prog.
 - Eames Bennett, P-3
 - Series of candidate designs exist
- Transferring candidate array designs to MCNP for optimization studies
 - e.g., reduce impact on measurement from environmental scattering, while maximizing efficiency

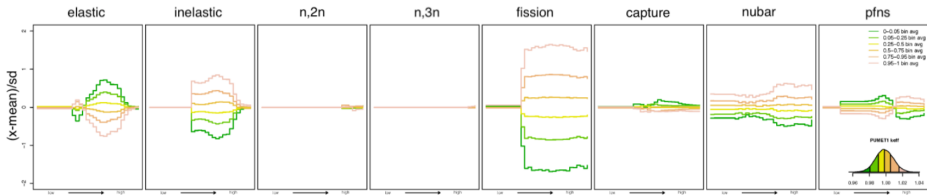


Response Matrix Technique *Required* for *n*-Det.

- Typical treatments of detection efficiency work poorly for neutrons
- Need complete description of n interactions with exp. environment
 - Especially for smooth distributions (e.g., high level density scattering)
- This was handled with MCNP for Chi-Nu PFNS measurements
 - The $^{35}\text{Cl}(n,p)$ cross section is poorly known...
 - Need an alternative method



Correlations Between Cross Sections

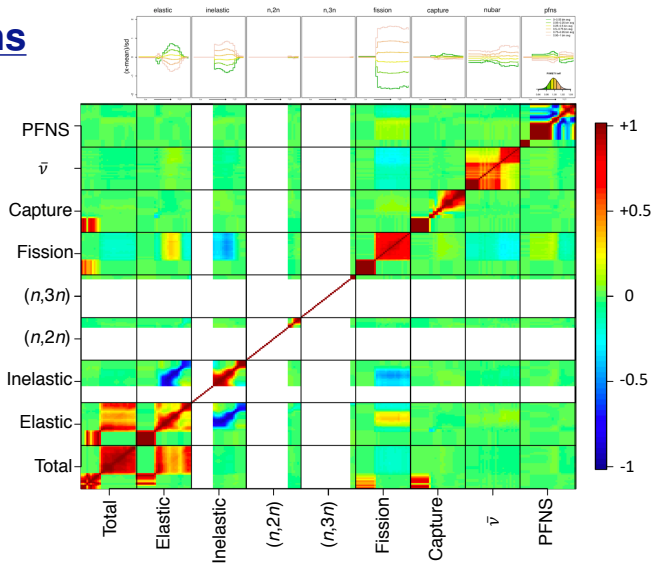


- See Sigeti *et al.* LA-UR-18-22053 and LA-CP-18-00796
- Also discussed at S. Mosby colloquium on 4/15 and WRIG on 4/6
- Correlations between ^{239}Pu cross sections from fitting to Jezebel critical assembly
 - Shows a, "...quantitative picture of compensating errors."
 - Strong prior correlations assumed between elastic and inelastic, to match total XS
 - 2D correlation matrices are more informative



XS Correlations

- Jezebel fitting enhanced el./inel. anticorrelation, but the correlations were already there!
- Anticorrelation came from evaluation requirement to sum to the total
- No experimental correlation input
- Exp. correlations are largely positive...



What if experimental elastic/inelastic correlations were reported?



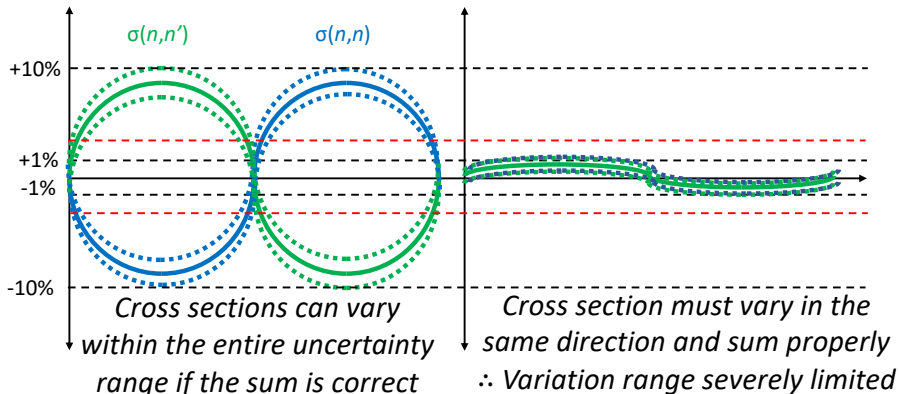
Correlated XSs Can Make a Big Impact!

Consider a nucleus with only elastic and inelastic scattering XS's

$$\left. \begin{aligned} \sigma(n,n) &= 1.0 \pm 0.1 \text{ b (10\% unc.)} \\ \sigma(n,n') &= 1.0 \pm 0.1 \text{ b (10\% unc.)} \end{aligned} \right\} \sigma(n,tot) = 2.0 \pm 0.04 \text{ b (2\% unc.)}$$

Anticorrelated or
No Correlation

Positive Correlation



Conclusions

- Promising capabilities with Chi-Nu liquid scintillator array
 - Limitations pointed towards another more ideal detector
- CLYC-6 detector array design in progress
 - CAD modeling → MCNP → Optimization
- Refinement of experimental techniques is required to properly use these detectors
 - Experimental detector response matrix
- Potential for correlated elastic and inelastic scattering cross section measurements
 - Also measure $(n,2n)$? $(n,3n)$? Total XS?
- Initial work funded by LDRD Project 20190588ECR
- Experimental measurement and development campaign underway through LDRD Project 20210329ER

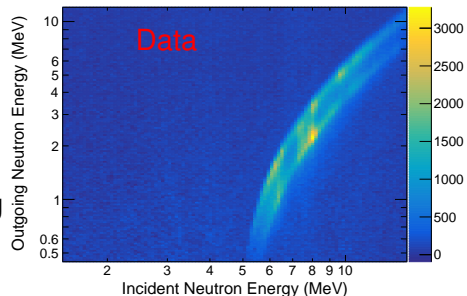
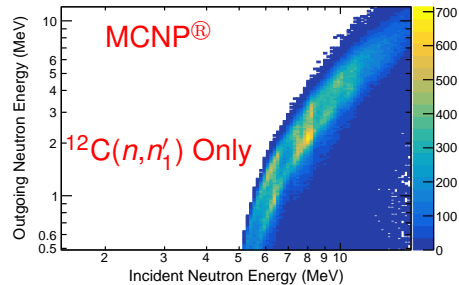
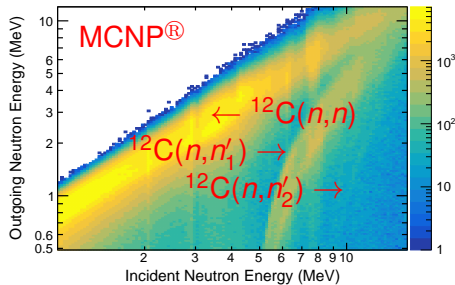
Thanks to Matt Devlin, John O'Donnell, Eames Bennett, Morgan White, the LANSCE accelerator staff, RMD inc., and you!



Backup Slides



MCNP Separates Rxns \Rightarrow Corrections per Rxn

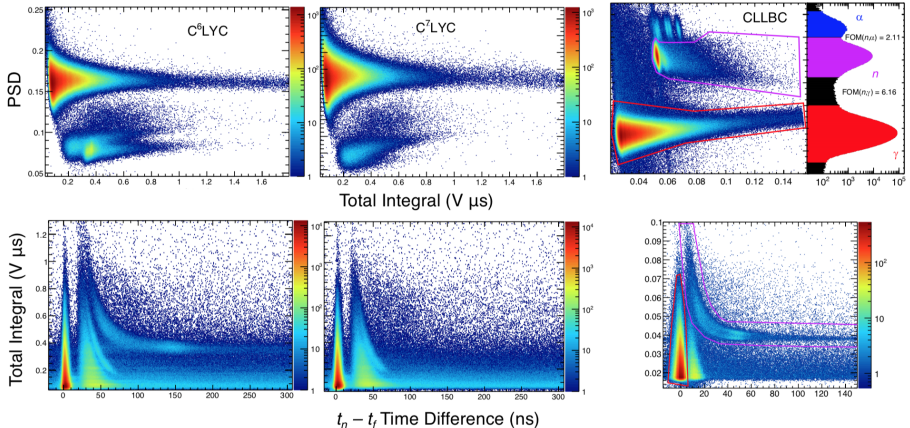


- MCNP[®] simulation of $^{12}\text{C}+n$ initially yields all reactions
- MCNP[®] + PTRAC allows for each reaction to be separated
- Can be used for in-target scattering and other corrections individually for each reaction



Kinematic and PSD Elpasolite Capabilities

- Beam-off ^{252}Cf measurements at two target-detector distances
- 1 m distance kinematics and PSD shown here
 - Near perfect PSD separation
 - n detection via $^6\text{Li}(n,t)$ and $^{35}\text{Cl}(n,p)$ reactions
 - Overlap in PSD space, but separable by kinematics with sufficient distance



Higher γ Response Ideal for γ -Coincident n 's

- Data from carbon can be compared to determine relative n - γ response
- Higher efficiency for γ than n in elpasolites (opposite of liquids)
 - Reduces chance of missing a γ for an inelastically scattered neutron
- CLLBC has very little neutron response

